Large Scale Structure:
Can we deliver what we promised?

Shirley Ho, Carnegie Mellon University

LSSTC and LSST-DESC
Large Scale Structure Working Group Chair
Presenting results also from
work within Planck and SDSS3-BOSS collaboration

Snowmass meeting,
July 30th, 2013

Carnegie Mellon University

BRUCE AND ASTRID MCWILLIAMS
Center for Cosmology

What do we want to do with BOSS/eBOSS/DESI/LSST large scale structure data ?

Main Science goals

- Dark Energy: Constraining the expansion rate of the Universe via ***Baryon Acoustic Oscillations***
- Ultimate test of non-gaussianities of the Universe? After Planck, large scale surveys is our best chance in probing fnl~1 level non-gaussianities, we can do this with LSST !
- Total Neutrino masses: When combined with WMAP9, SDSS3 imaging data gives already a very stringent constraint of 0.26eV (95% CL)
- Dark Matter: We can probe modified gravity with *redshift space distortions*, and by combining with lensing, we can understand the bias of our tracers as a function of scale and redshift.

What are Baryon Acoustic Oscillations (BAO) anyway?

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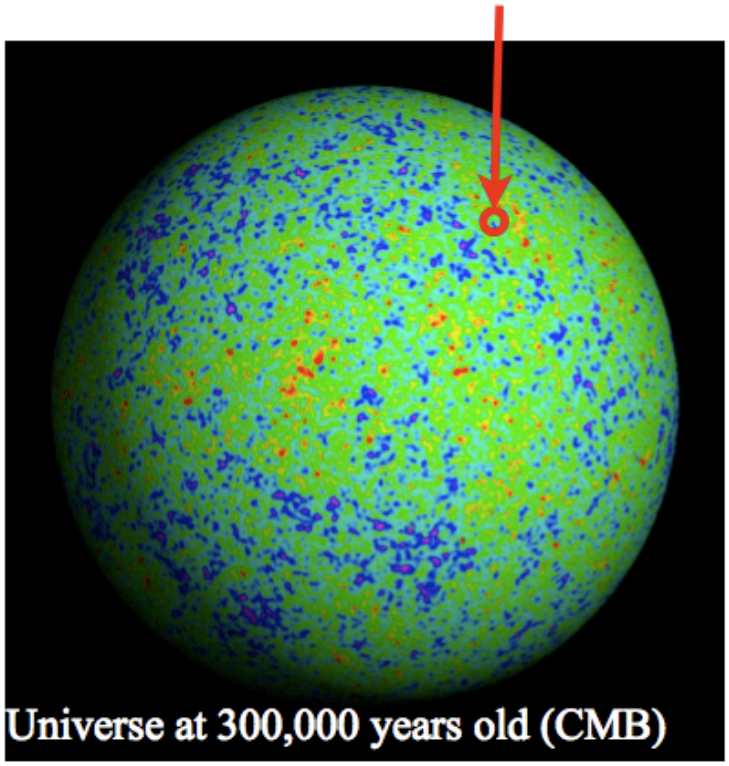
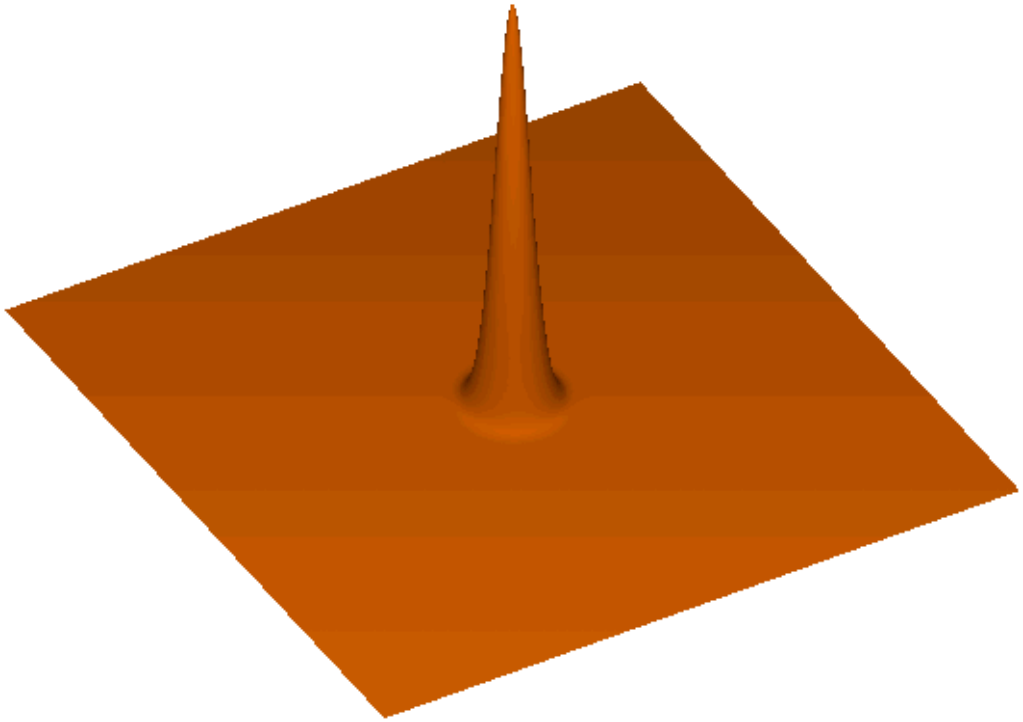
These fluctuations of 1 part in 10^5 gravitationally grow into...





This sound wave can be used as a "standard ruler"
Dark energy changes this apparent ruler size

Courtesy slide from David Schlegel and animation from Daniel Eisenstein

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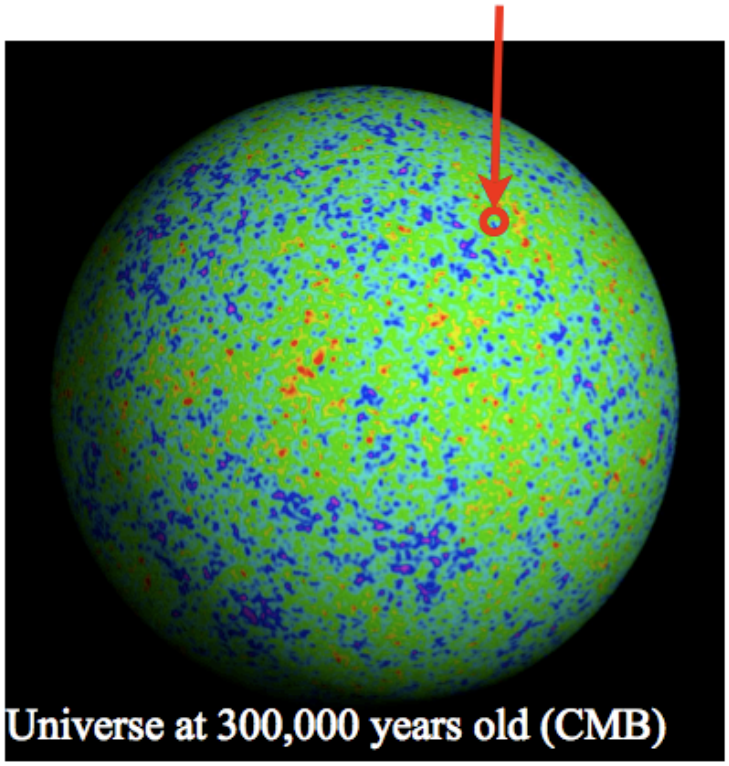
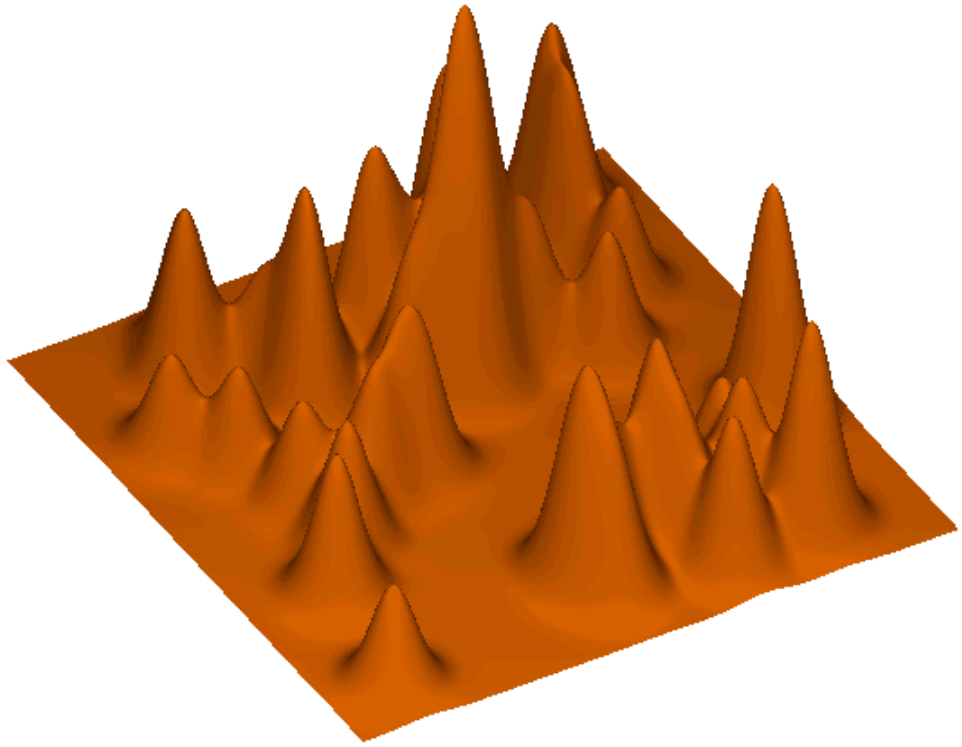


...these ~unity fluctuations today



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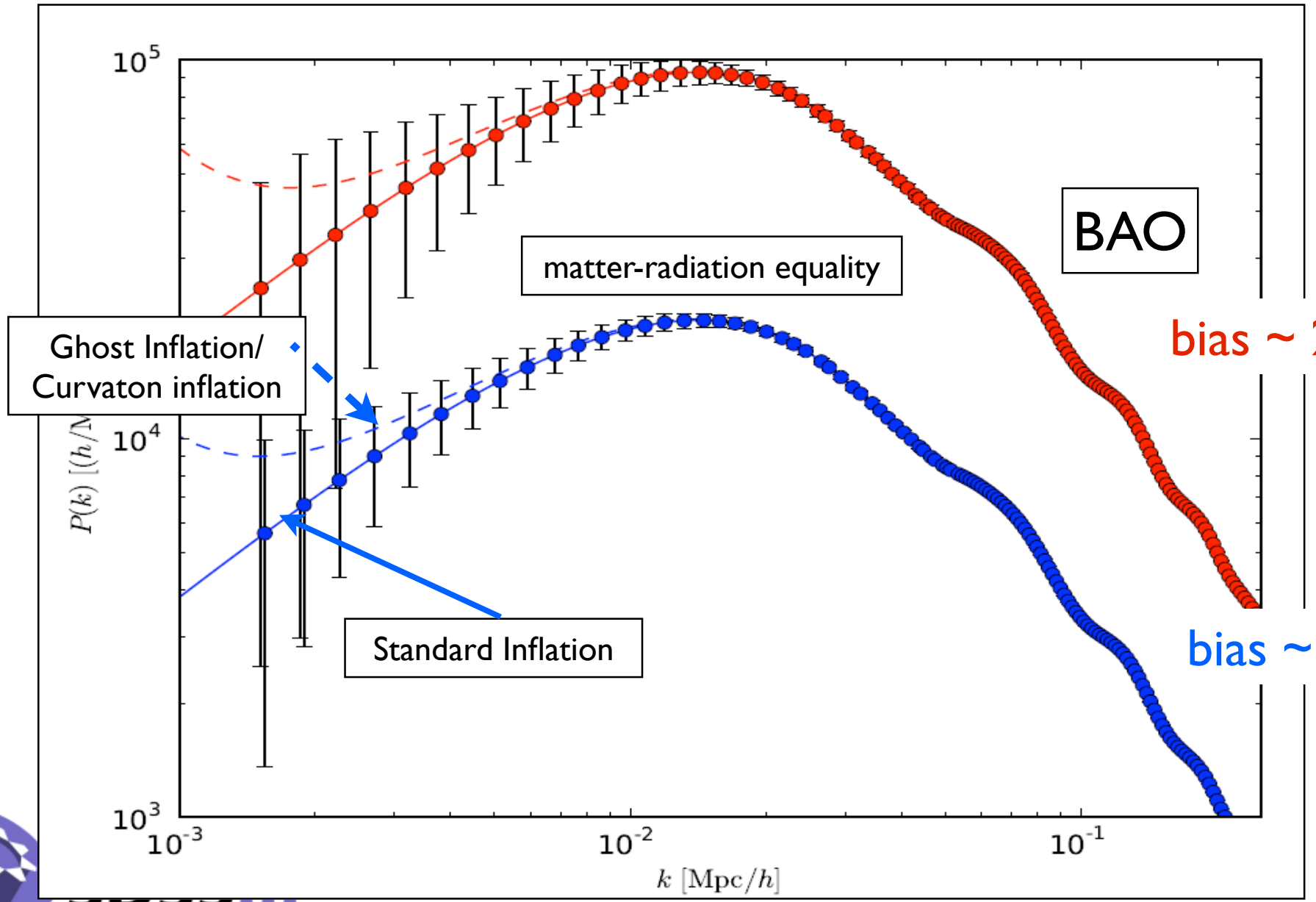
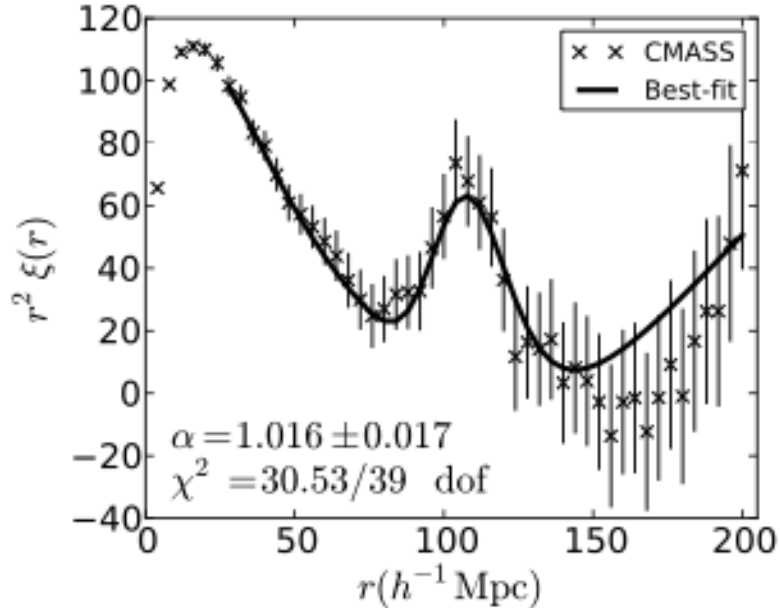
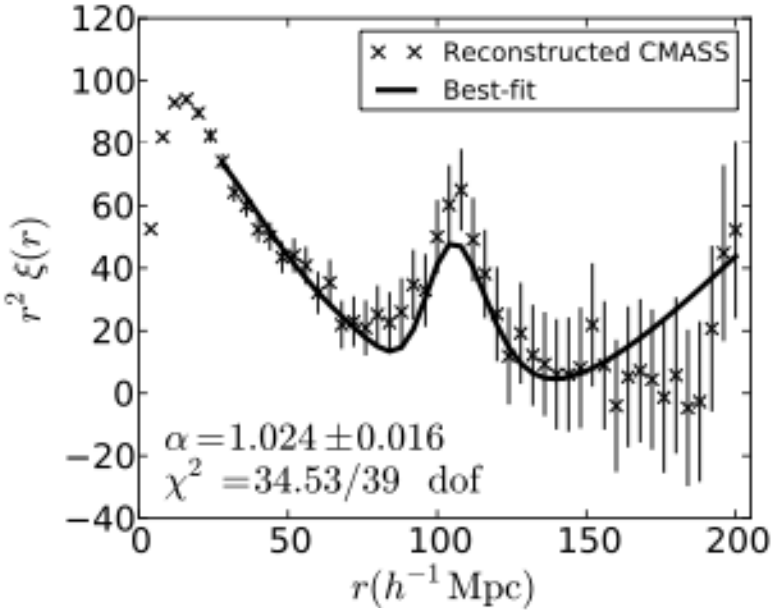
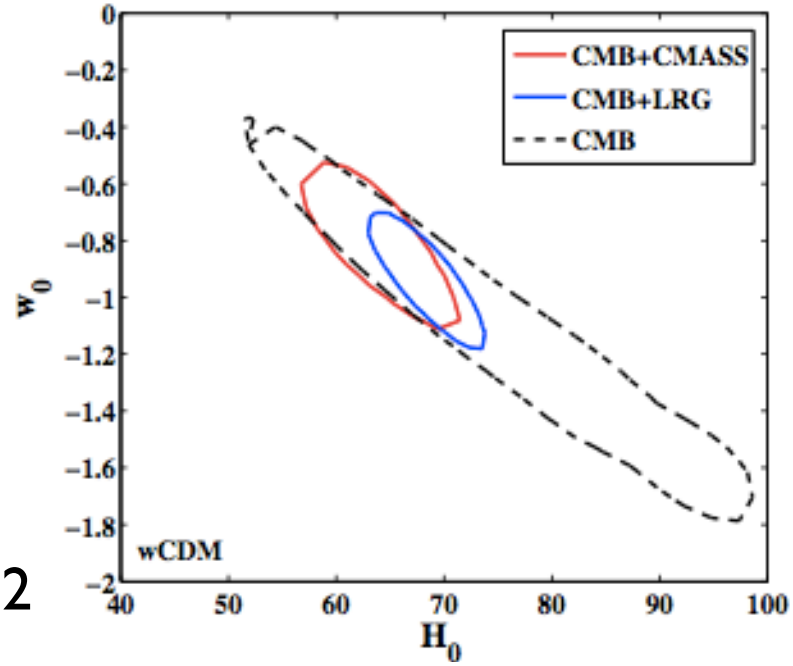
Clustering in 3D



So we can do BAO in spectroscopic data like BOSS and SDSS!

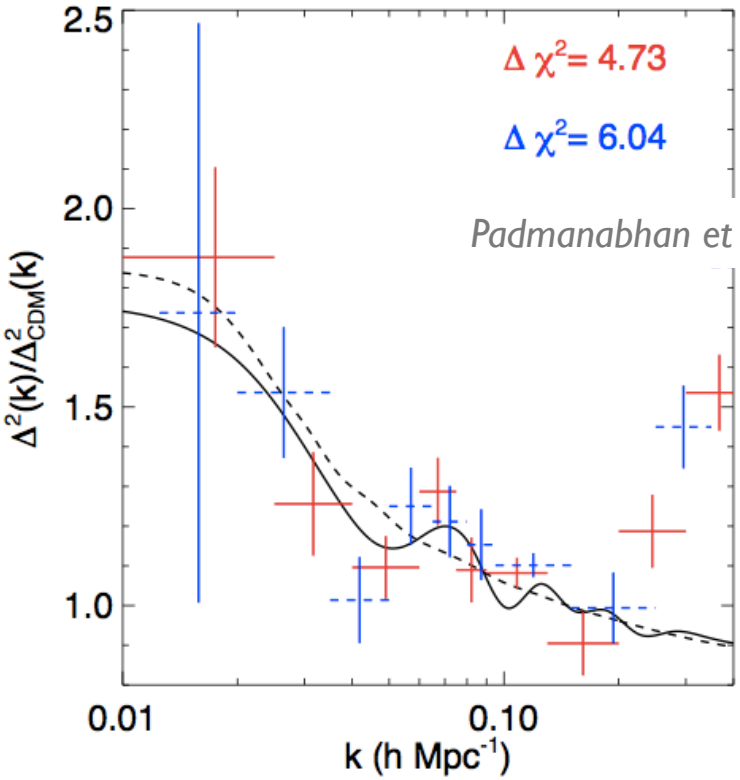






BOSS collaboration 2012

AND we can do BAO in imaging data also (not only spectroscopic!)



Padmanabhan et al. 2006

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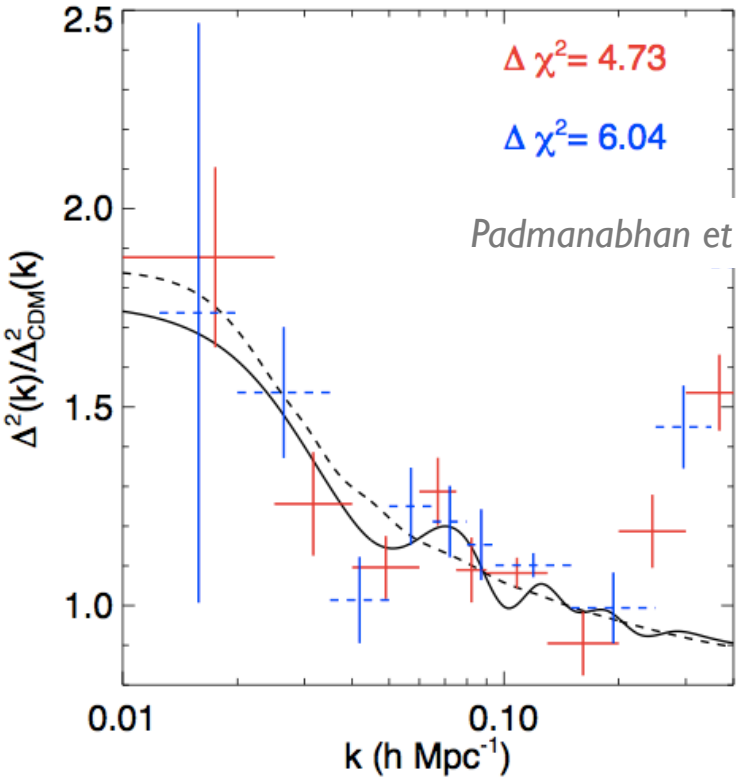

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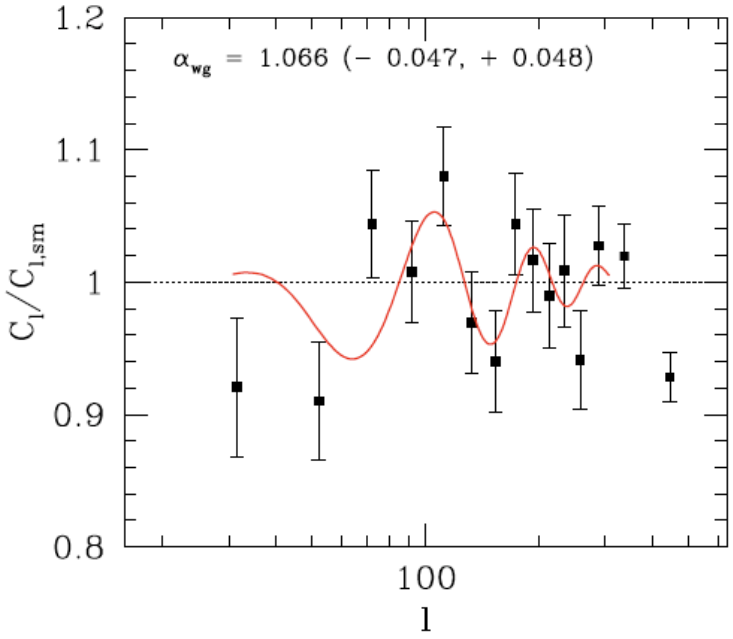
S. Ho, Cuesta, Seo, Ross, DePutter et al. (2012)

Seo, S.Ho, White et al. (2012)



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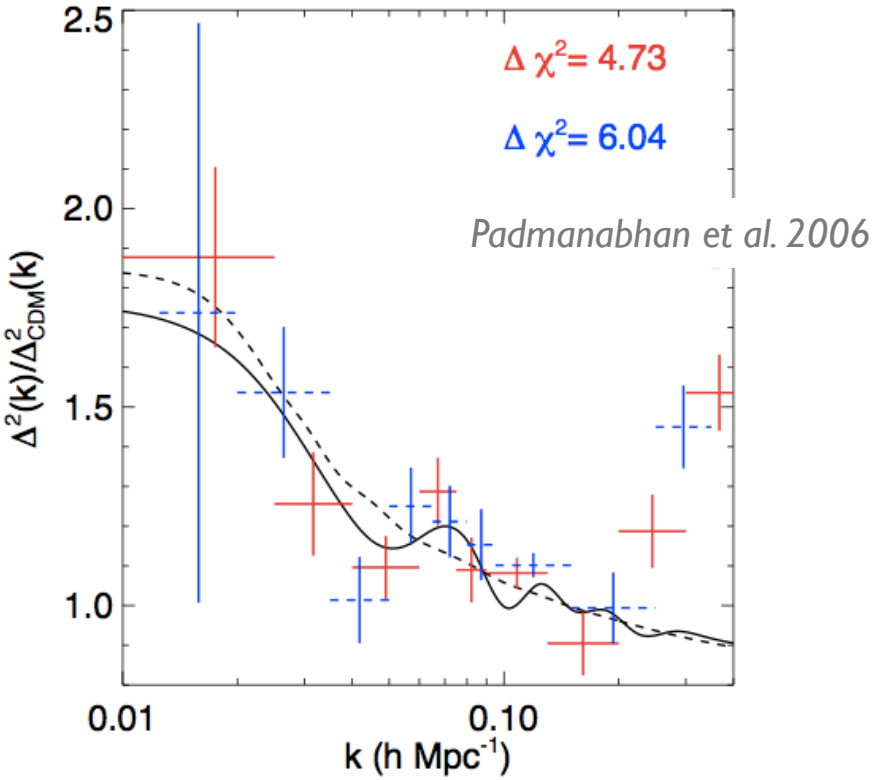

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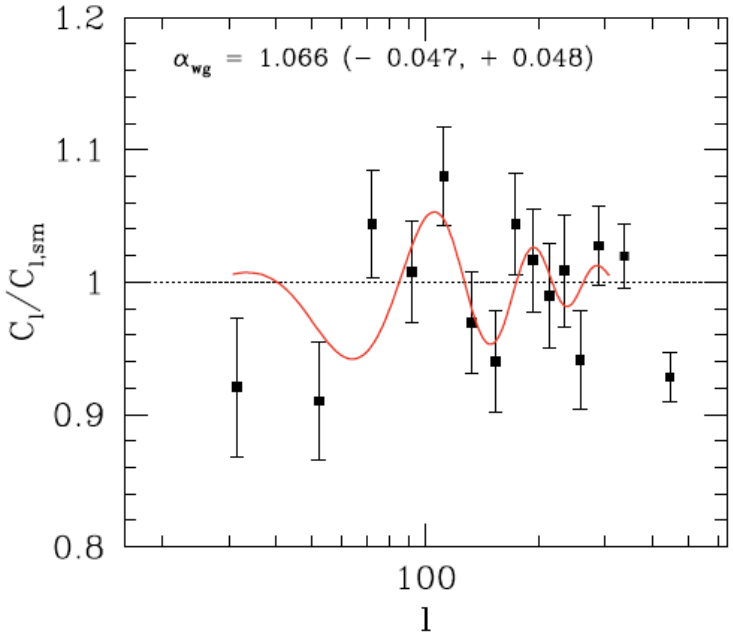
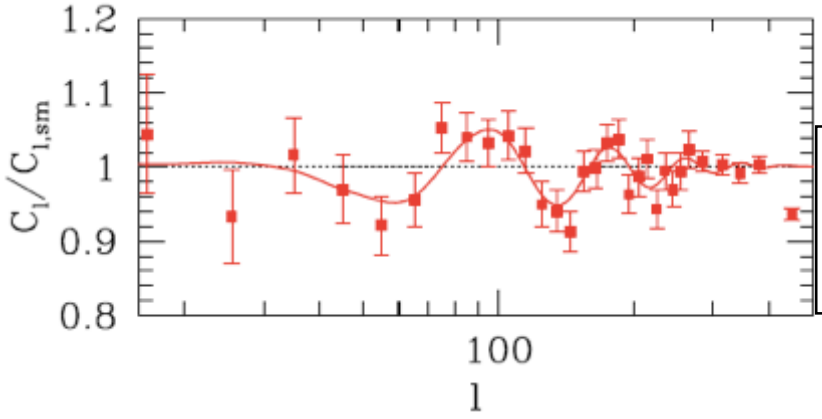
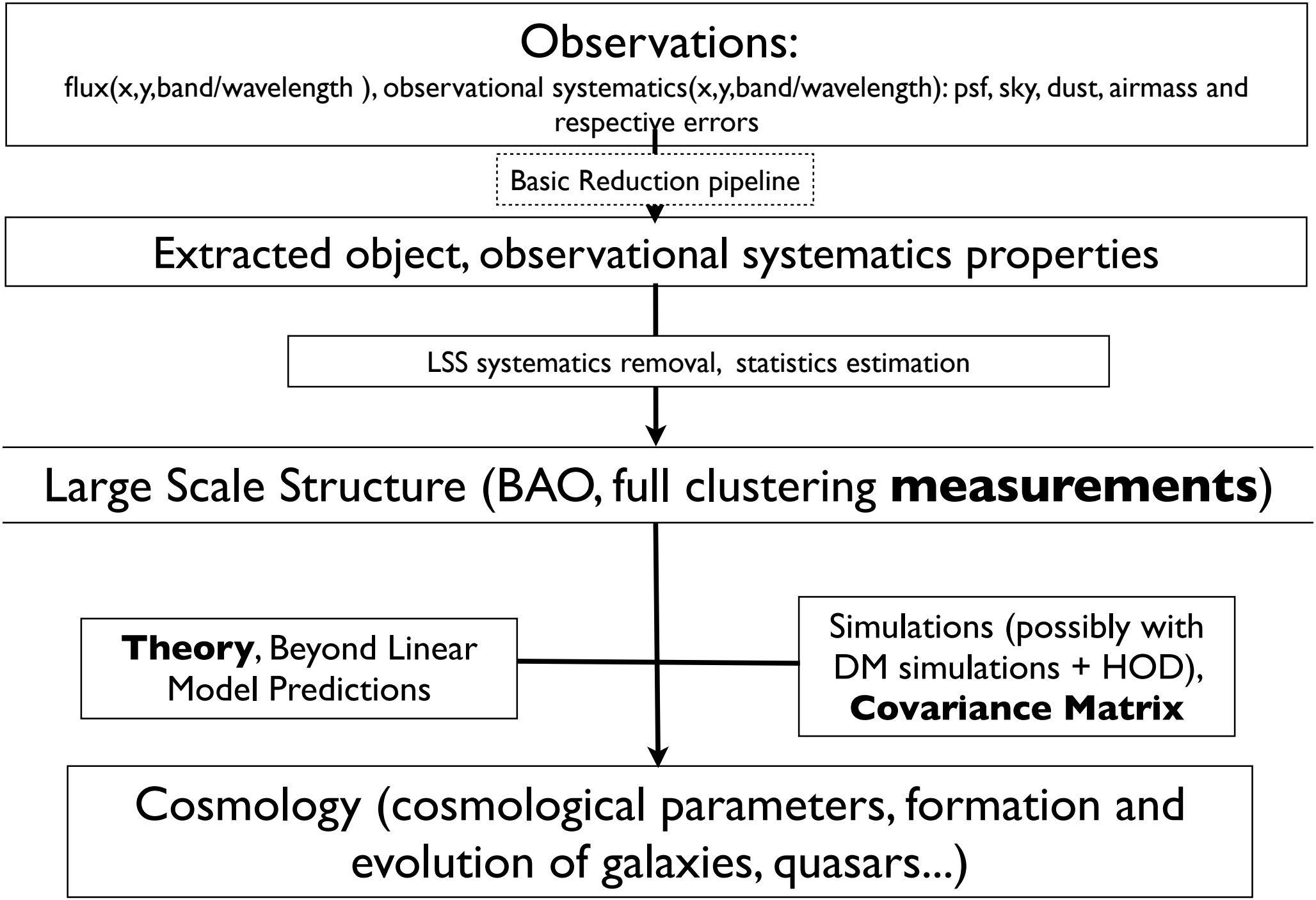




This is what we expect if we have 4 times more volume,
and
in LSST, we have a lot more than 4 times volume in SDSS

Shirley Ho

So how do we do this Large Scale Structure measurement?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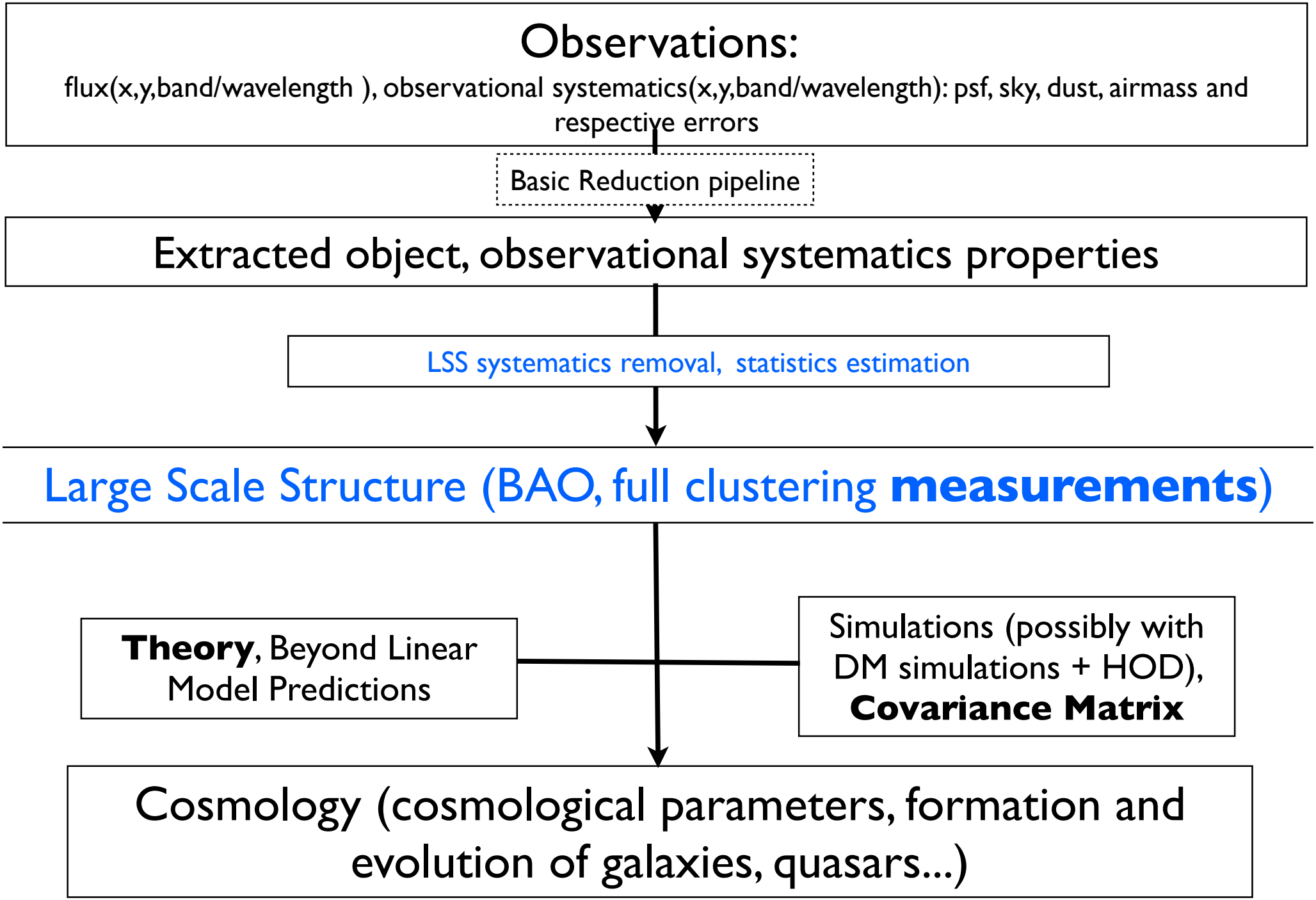
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The First Challenge

- **Mak**
  - Cr ction function pr

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  - Creating the sample, and the selection function properly

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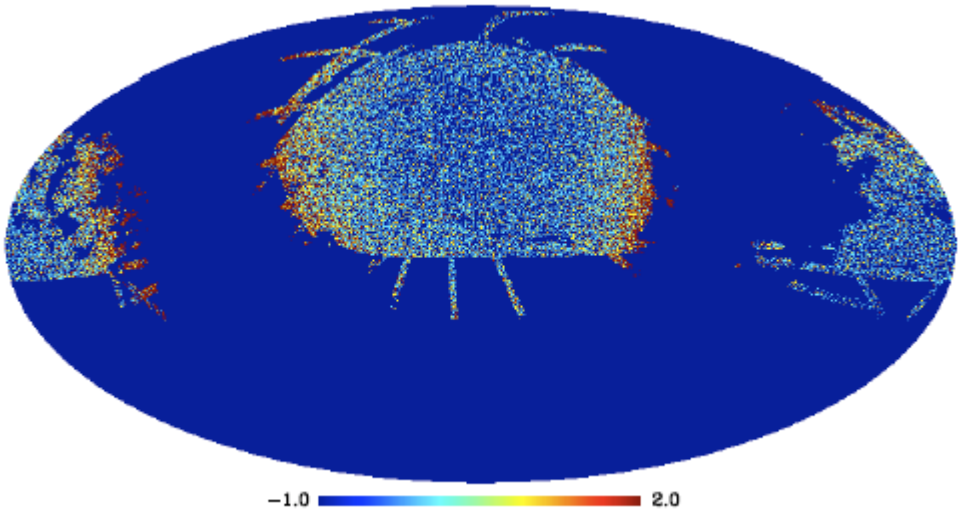
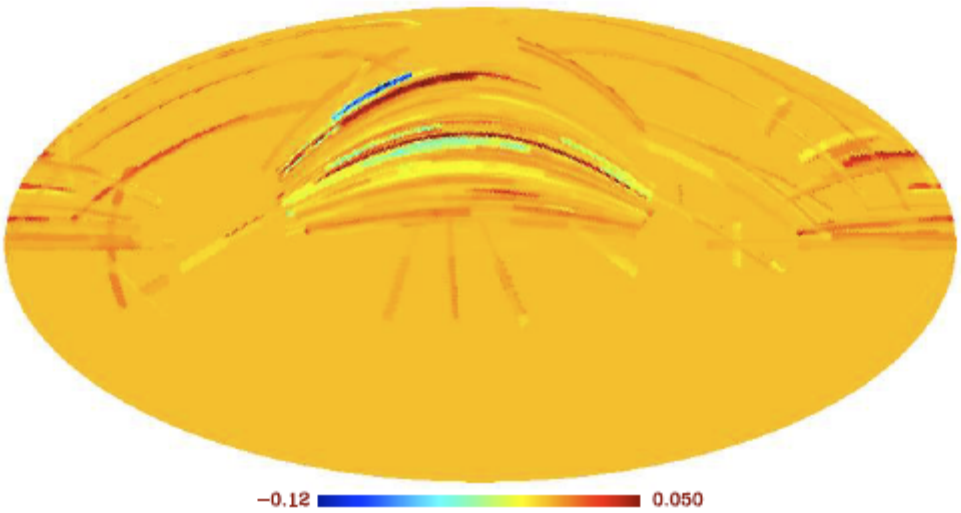
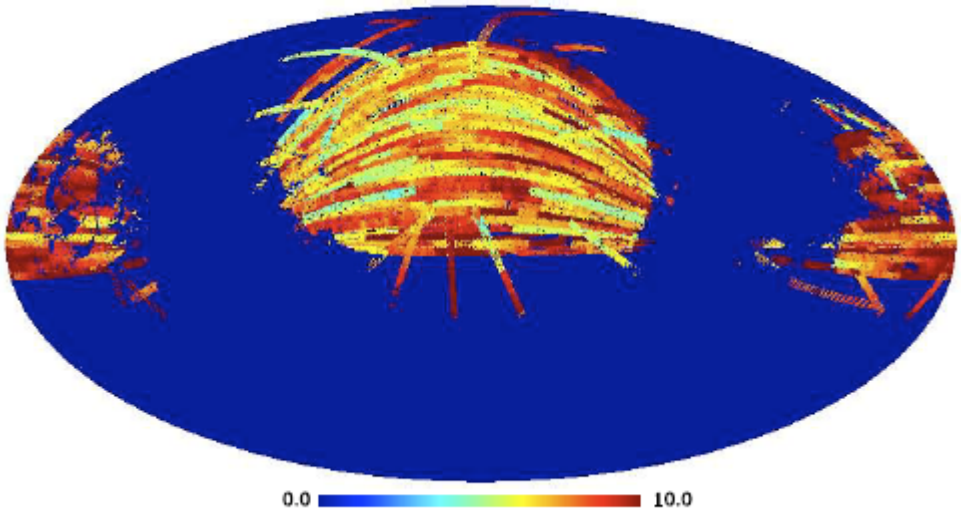
Stars !



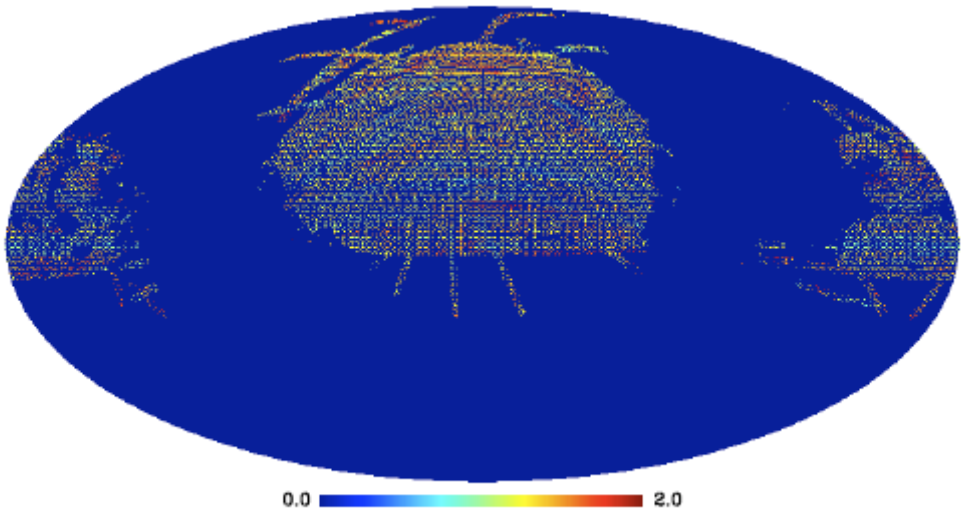
Color offsets from Schlafly et al. 2011



Sky Brightness



Seeing



SH, Cuesta, Seo, Ross, DePutter et al. (2012), Ross, SH et al. (2011)

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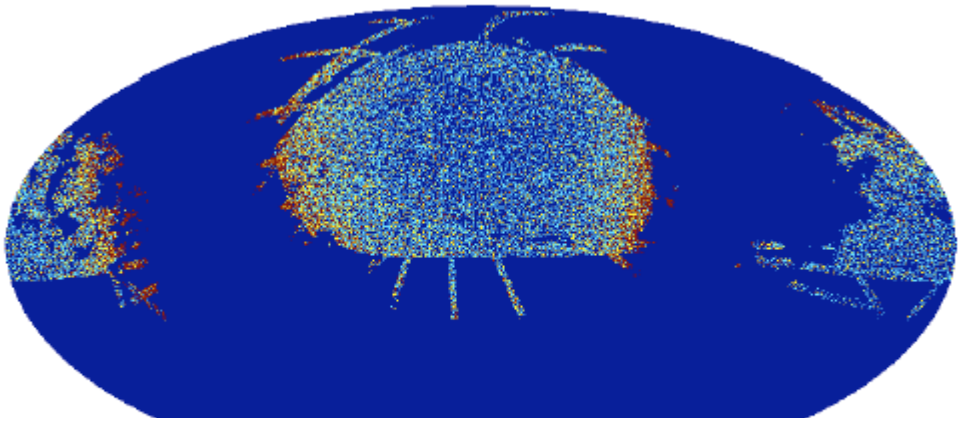
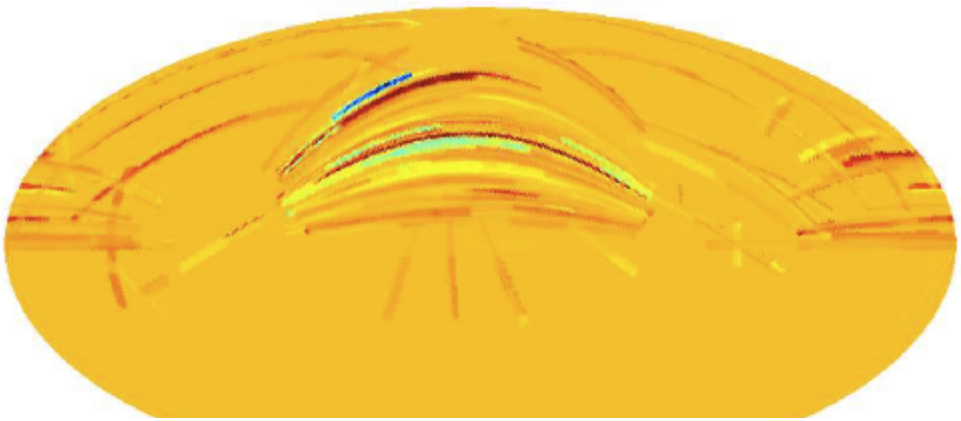
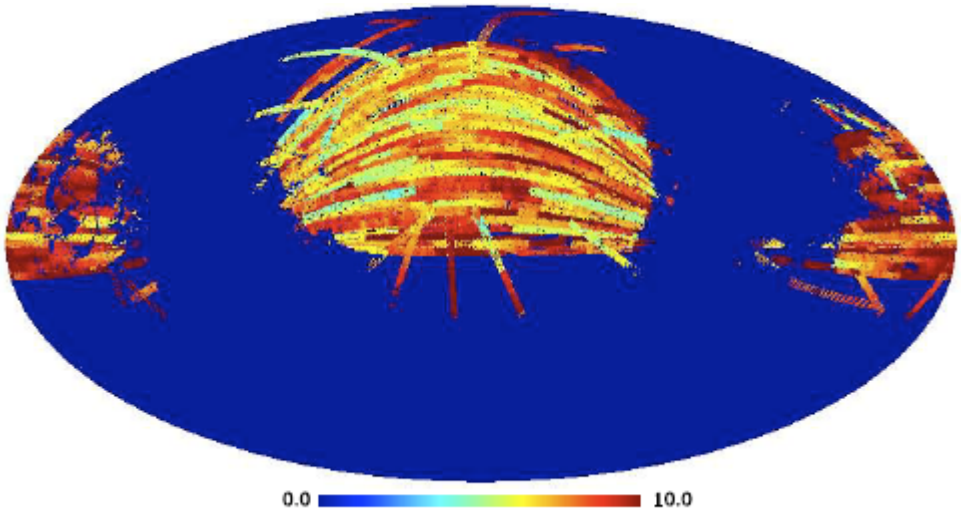
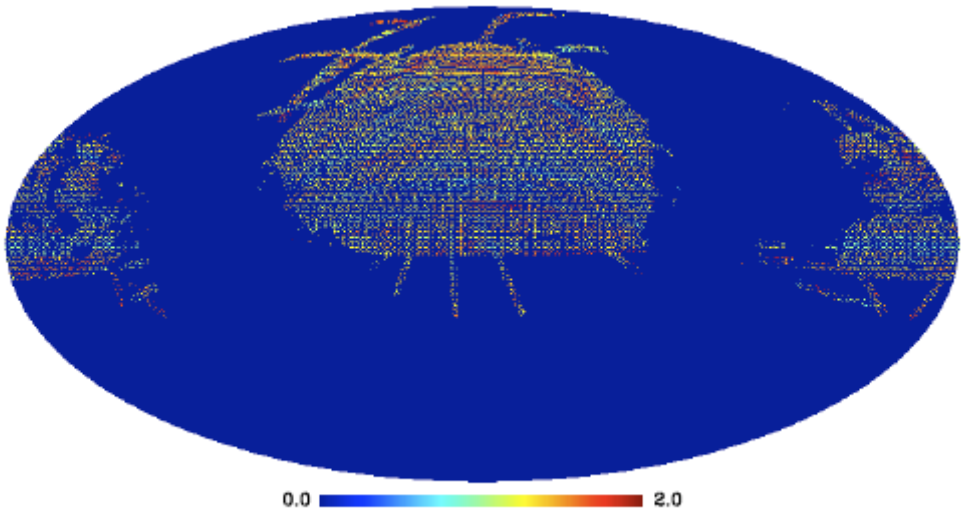




The samples you can gleam from the sky
is not a fair sample of the Universe, but rather a real Universe
convolved with all the lovely observational systematics





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Short summary:

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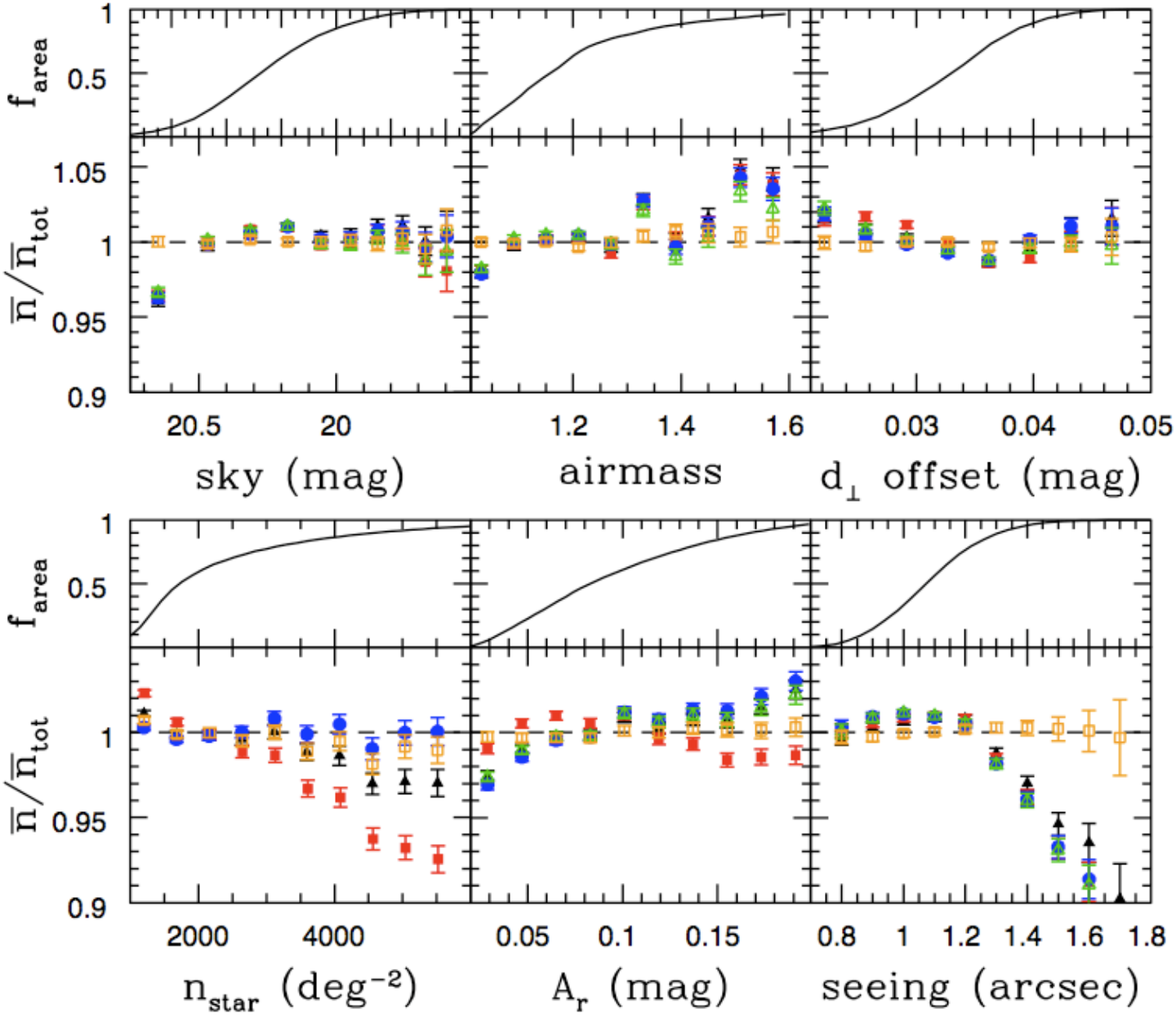

Ross, SH, Cuesta et al. (2011)

Partial answers to The First Challenge

- Setting systematic weights for each galaxy, so that the effects of observational systematics are minimized (Ross, SH et al. 2011, Ross et al. 2012)
- Projecting out systematics by using systematic templates (Pullen & Hirata 2012, Slosar et al. 2013, Huterer et al. 2013)
- Cross-correlating observed densities with systematics to remove the effects of systematics on the over-densities (Myers et al. 2008, SH, Cuesta et al. 2012)
- Cross-correlating multiple redshift slices to detect unknown observational systematics (Agarwal, SH et al. 2013)

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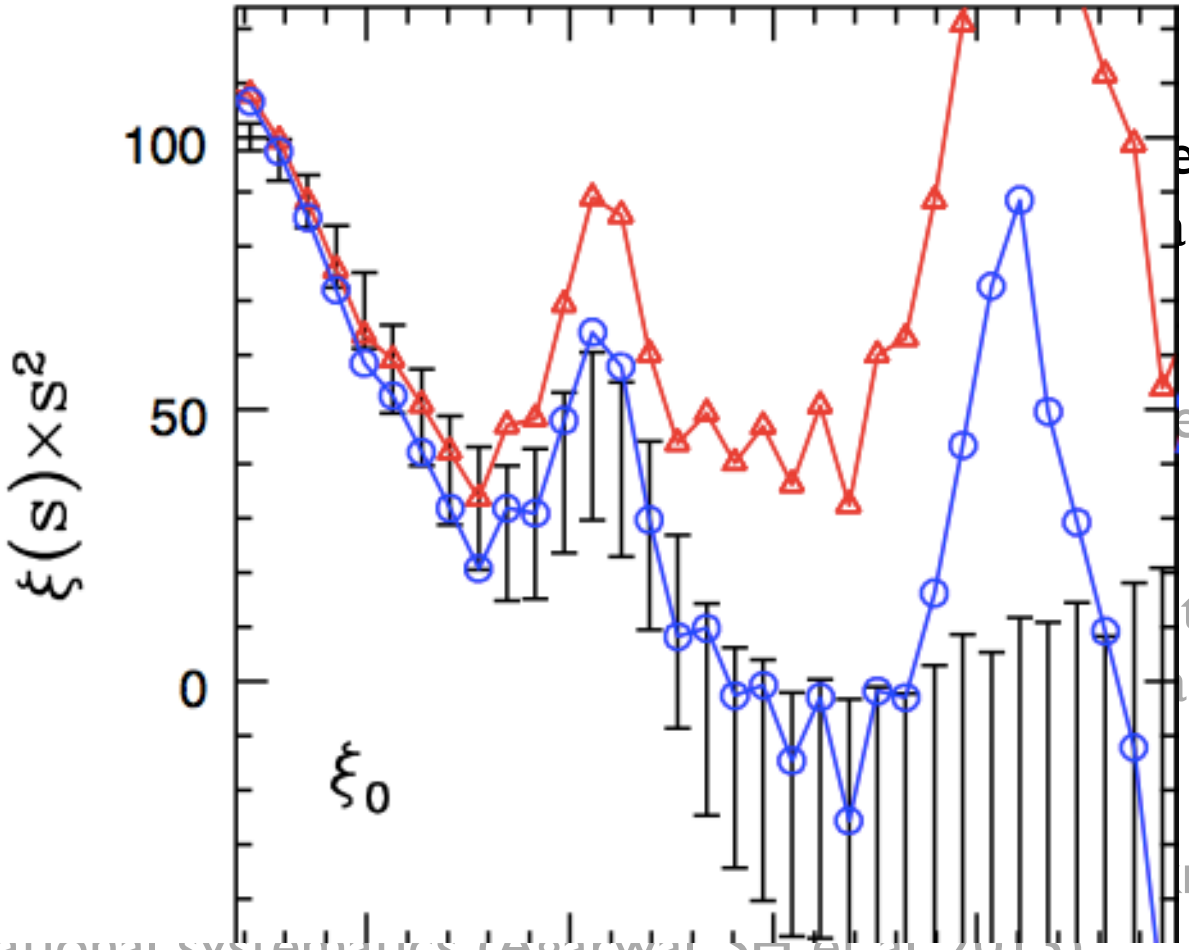

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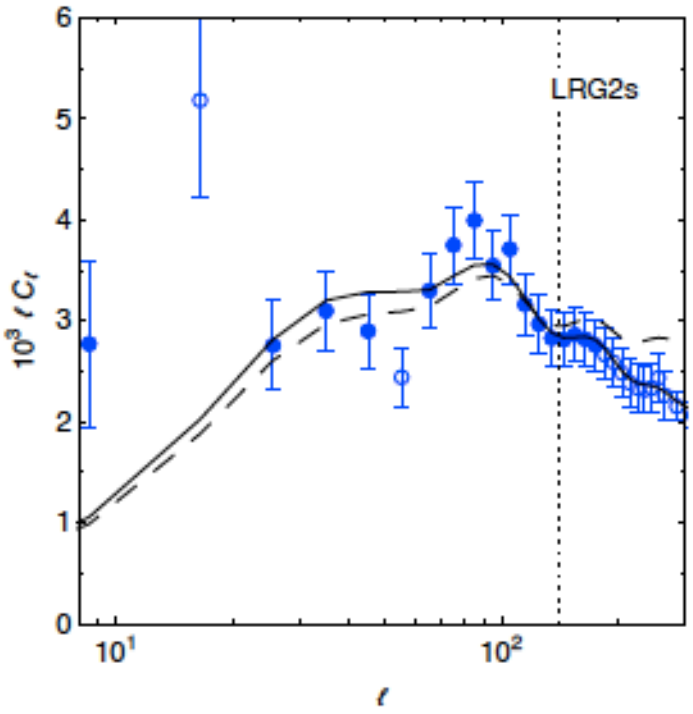
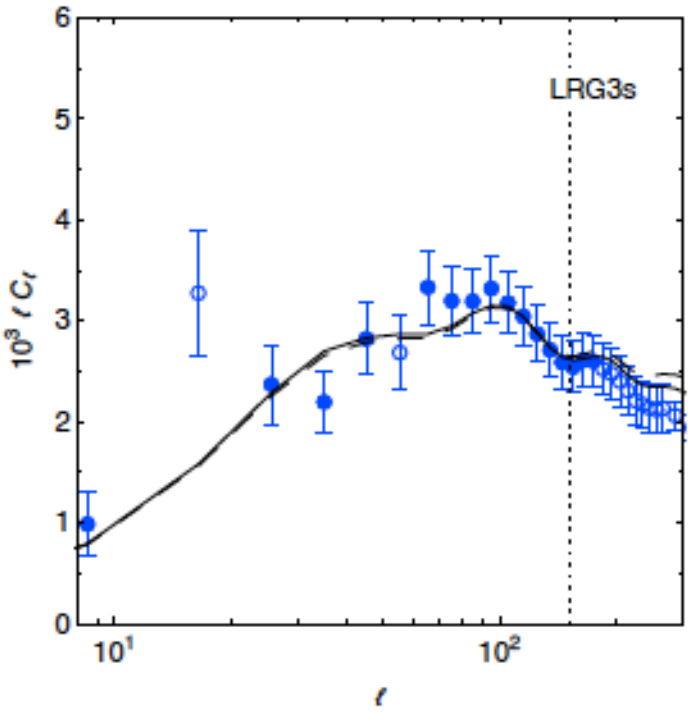
- 



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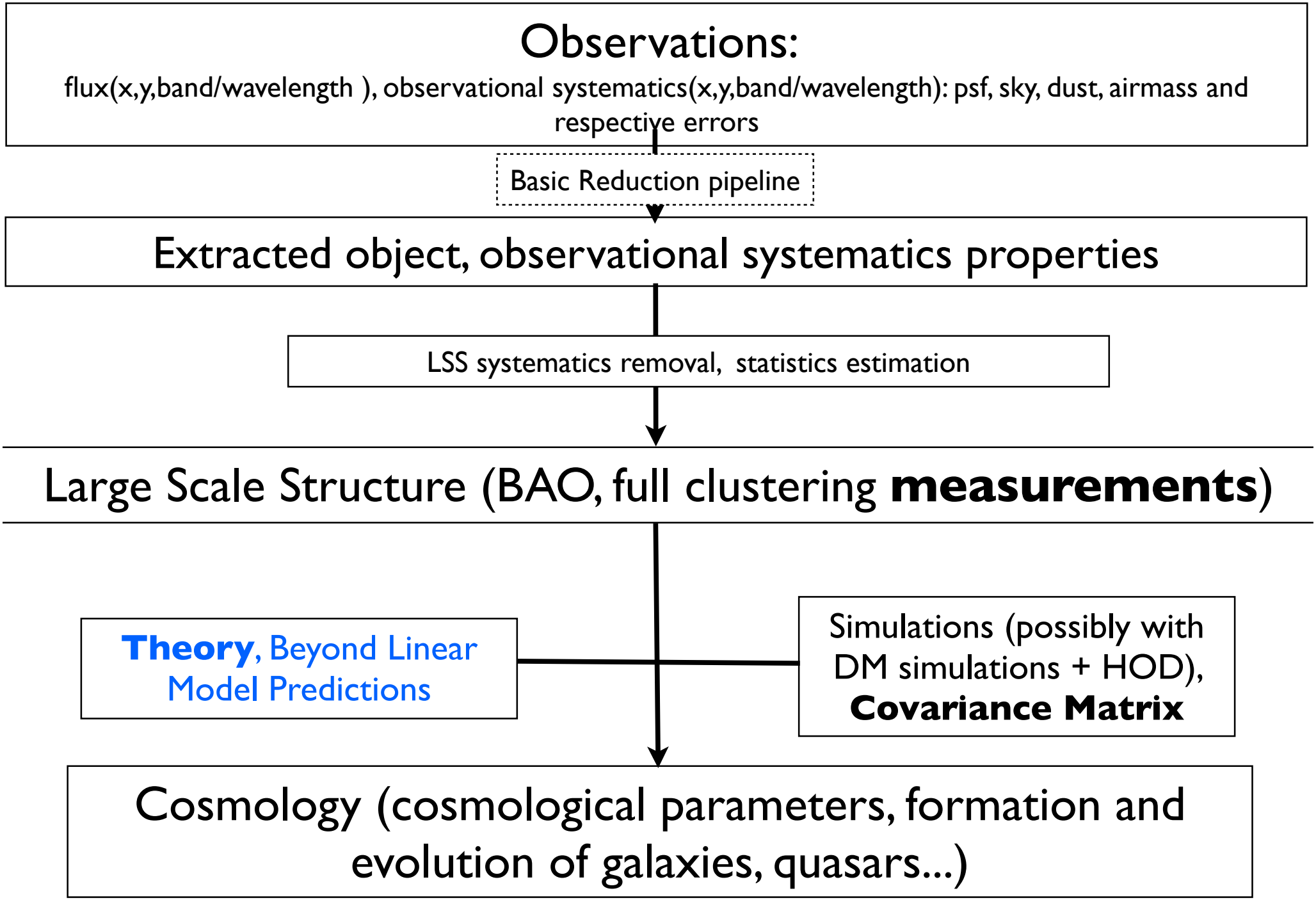
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Yes, the theory of large scale structure is non-trivial:

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Observation:

redshift space galaxy correlation function

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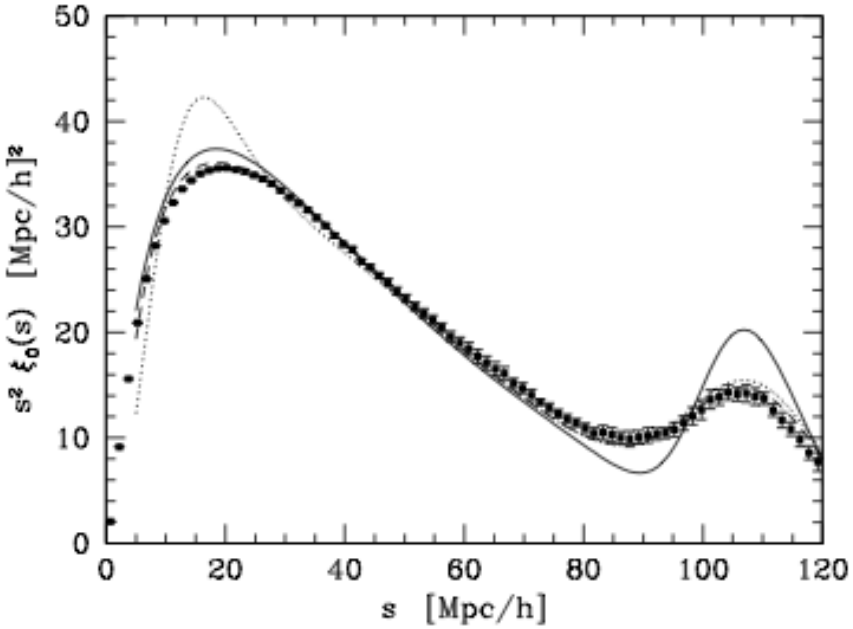
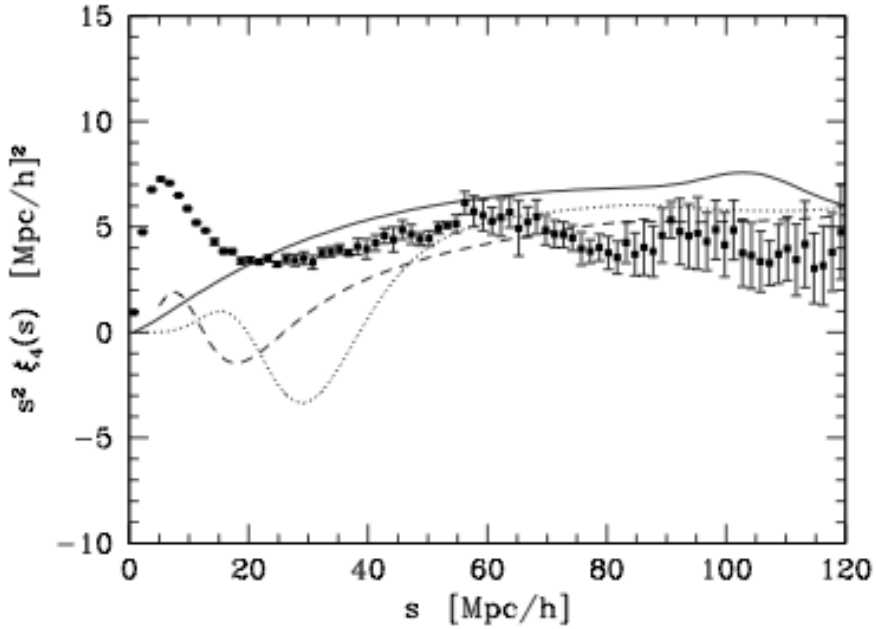
What we can confidently predict:

real space dark matter correlation function

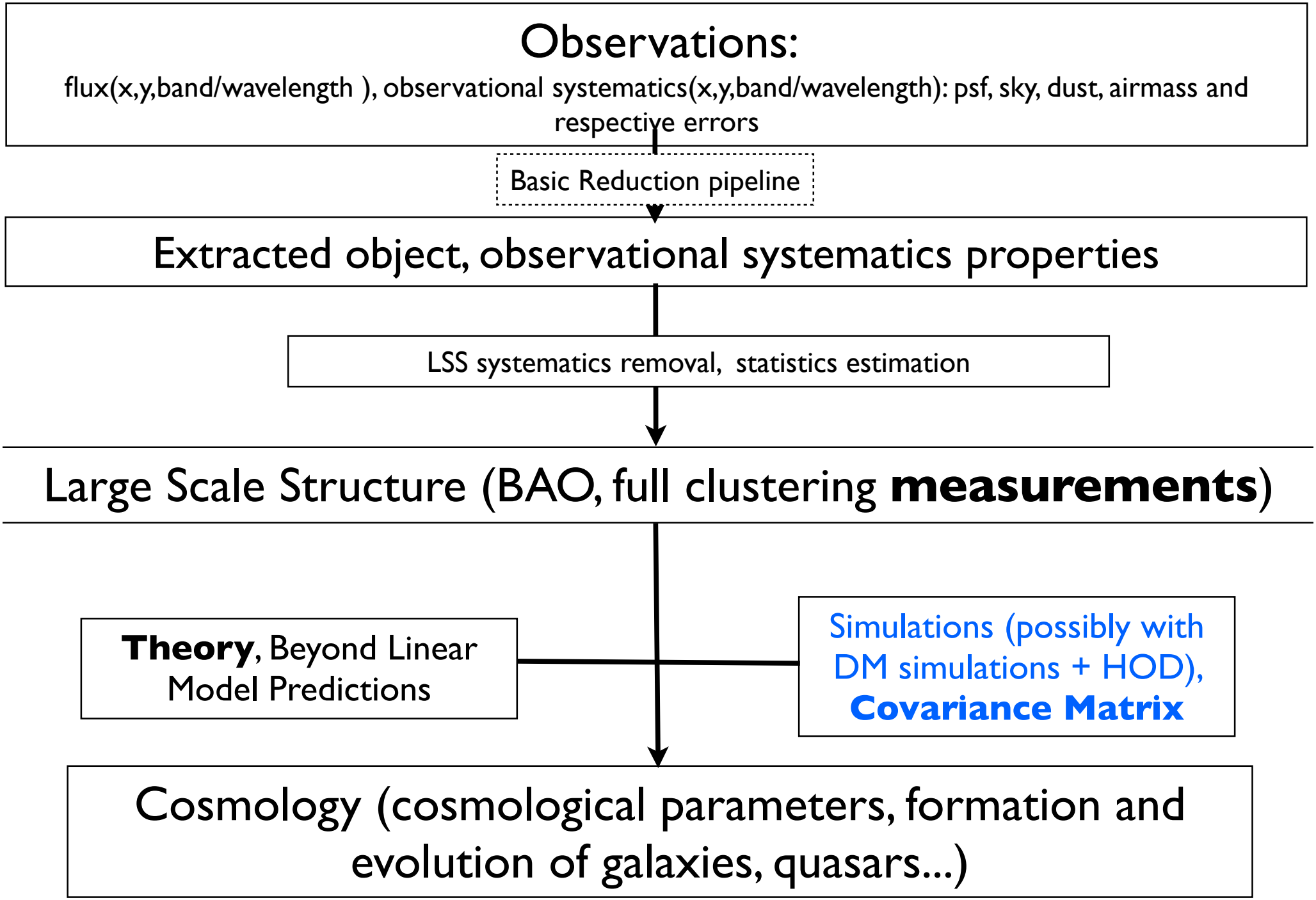
Current theory vs Simulations





Solid lines: Linear Theory
Points: N-body simulations

Carlson, Reid and White 2012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The Third Grand challenge

- In orde riance matrix easy and dumbes *the whole observat* ee what is the vari s.
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- Can we

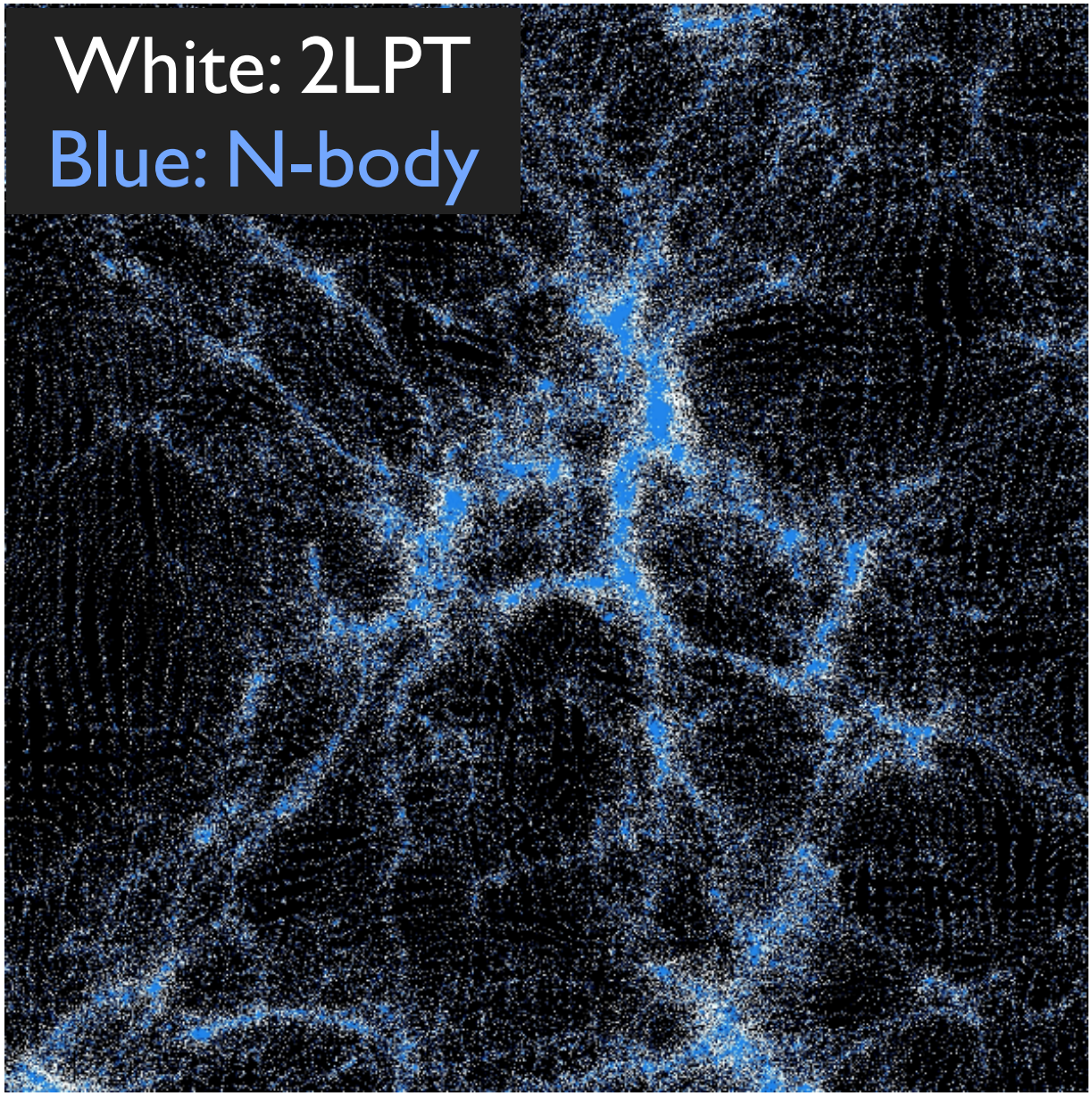
The Third Grand challenge

- In order to generate reliable covariance matrix of our measurements, the easy and dumbest thing to do is to *simulate the whole observation many many times*, and see what is the variance across the simulations.
- But this *can be* Very expensive for a large scale observation such as LSST
- The second and third challenge can in principle be solved by increased ability to generate synthetic Universes

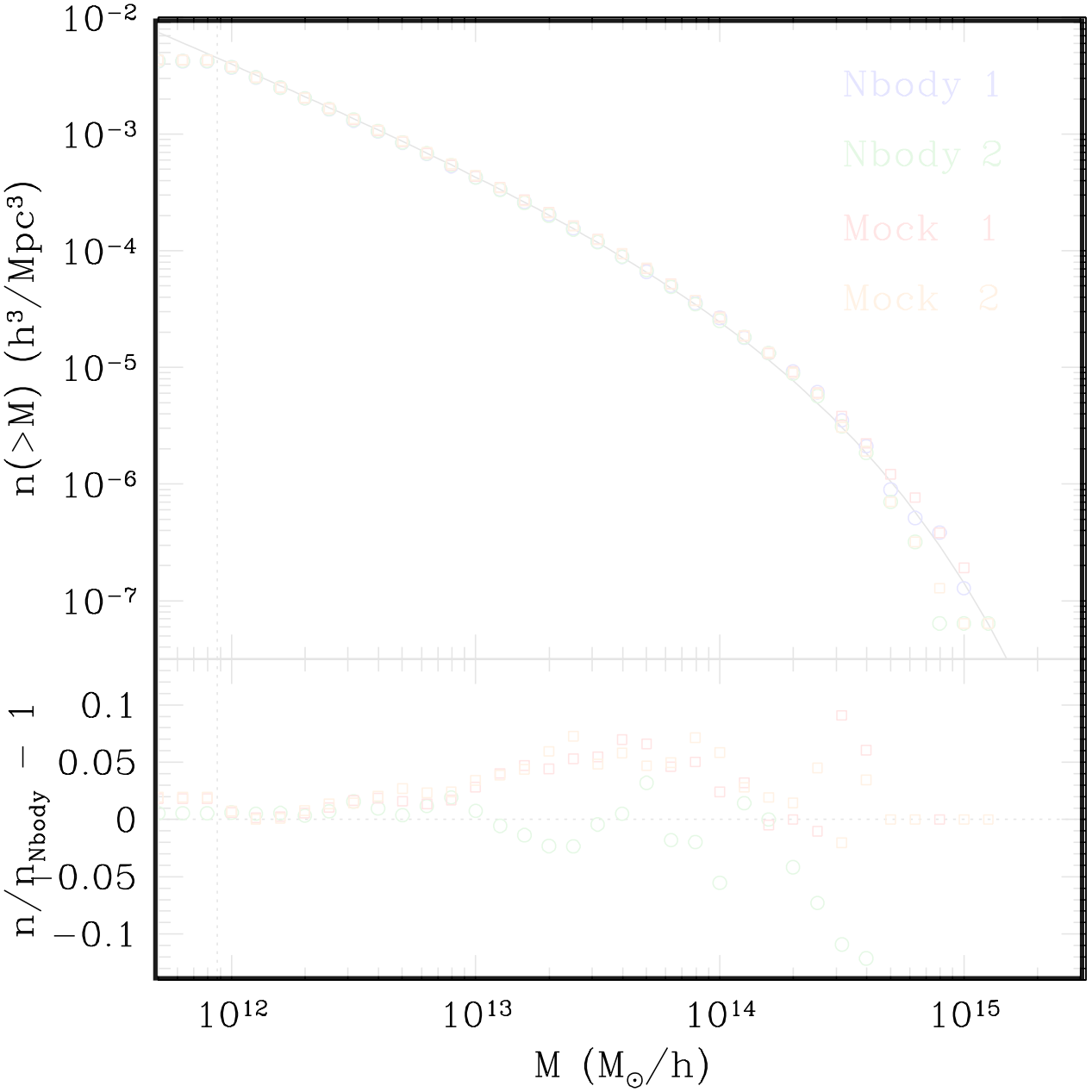
Generating Synthetic Universes

- The generation of synthetic Universe usually separated into two steps:
  - Creating Density field
    - Transformation of gaussian field (Coles 1992),
    - Perturbation theory like solution: PINNOCHIO (Monaco et al. 2002), 2LPT code (Scoccimaro & Sheth 2002), COLA (Tassev & Zaldarriaga 2013))
  - Painting galaxies onto the density field
    - Halo Occupation Distribution (Peacock & Smith 2002, Cooray & Sheth 2002, ..)
    - Semi-Analytical models (White 1978)

Other newer alternatives: Use Machine Learning to evolve the density field?



Very preliminary test: let's compare the halos statistics



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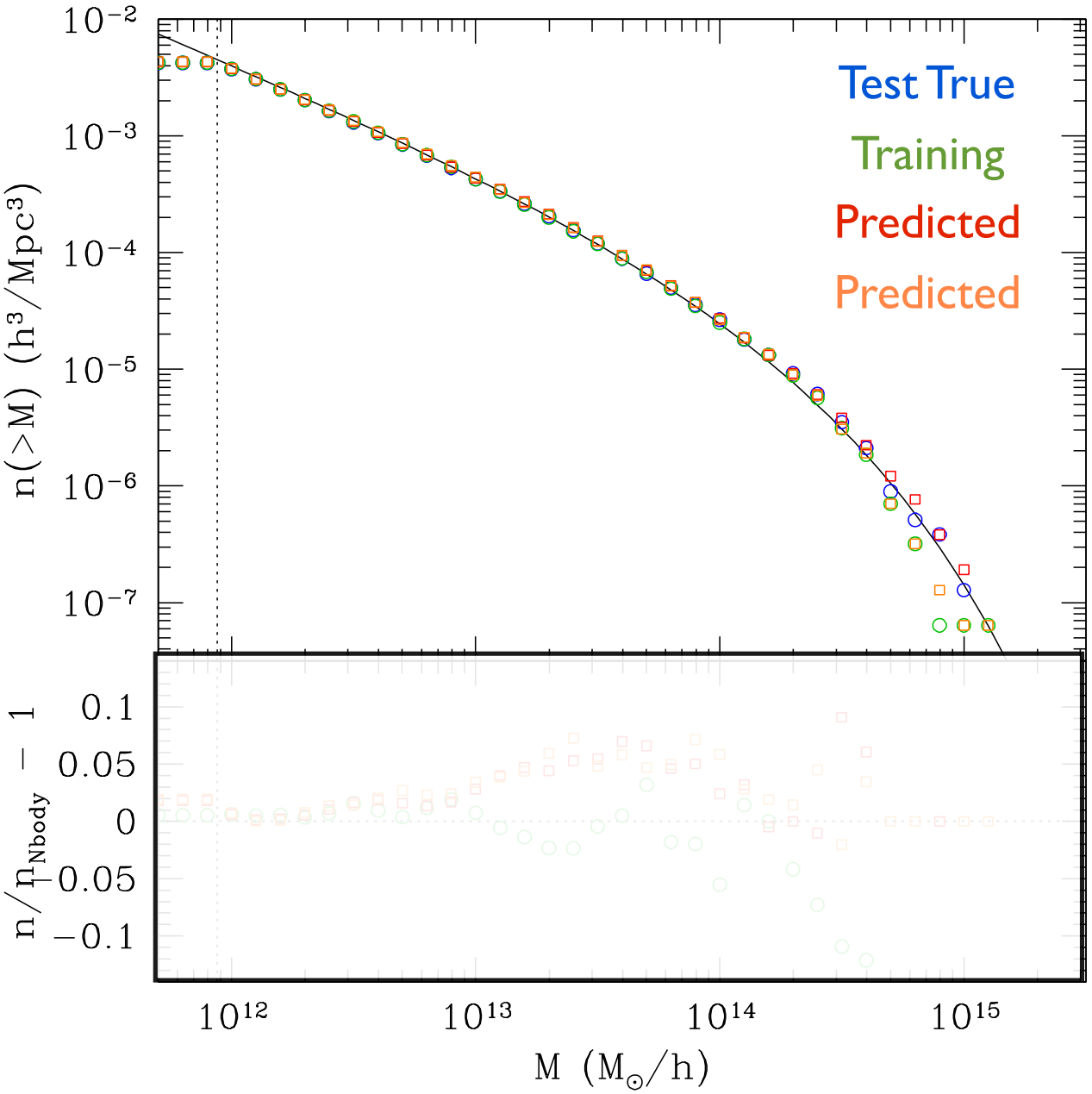

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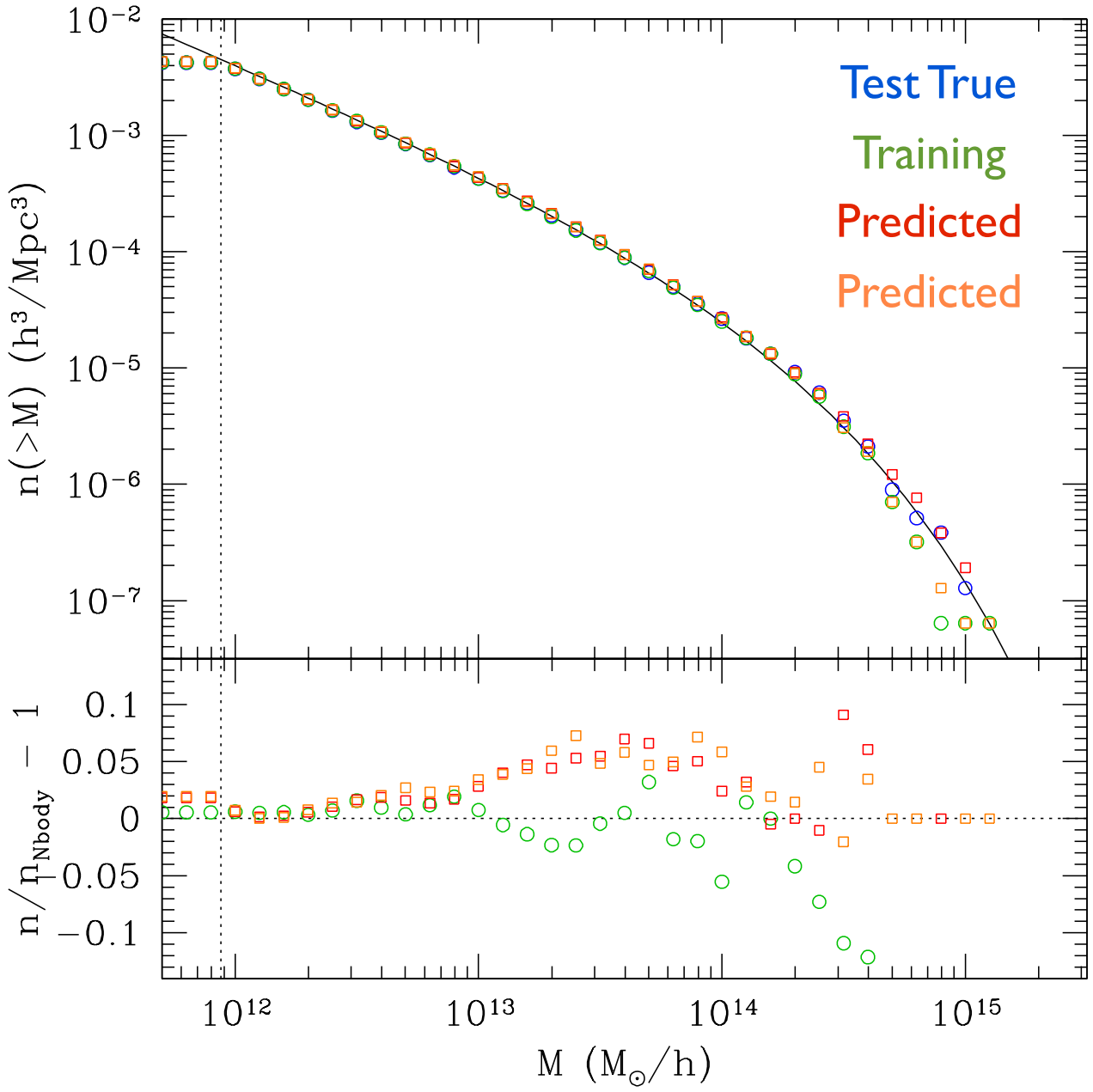
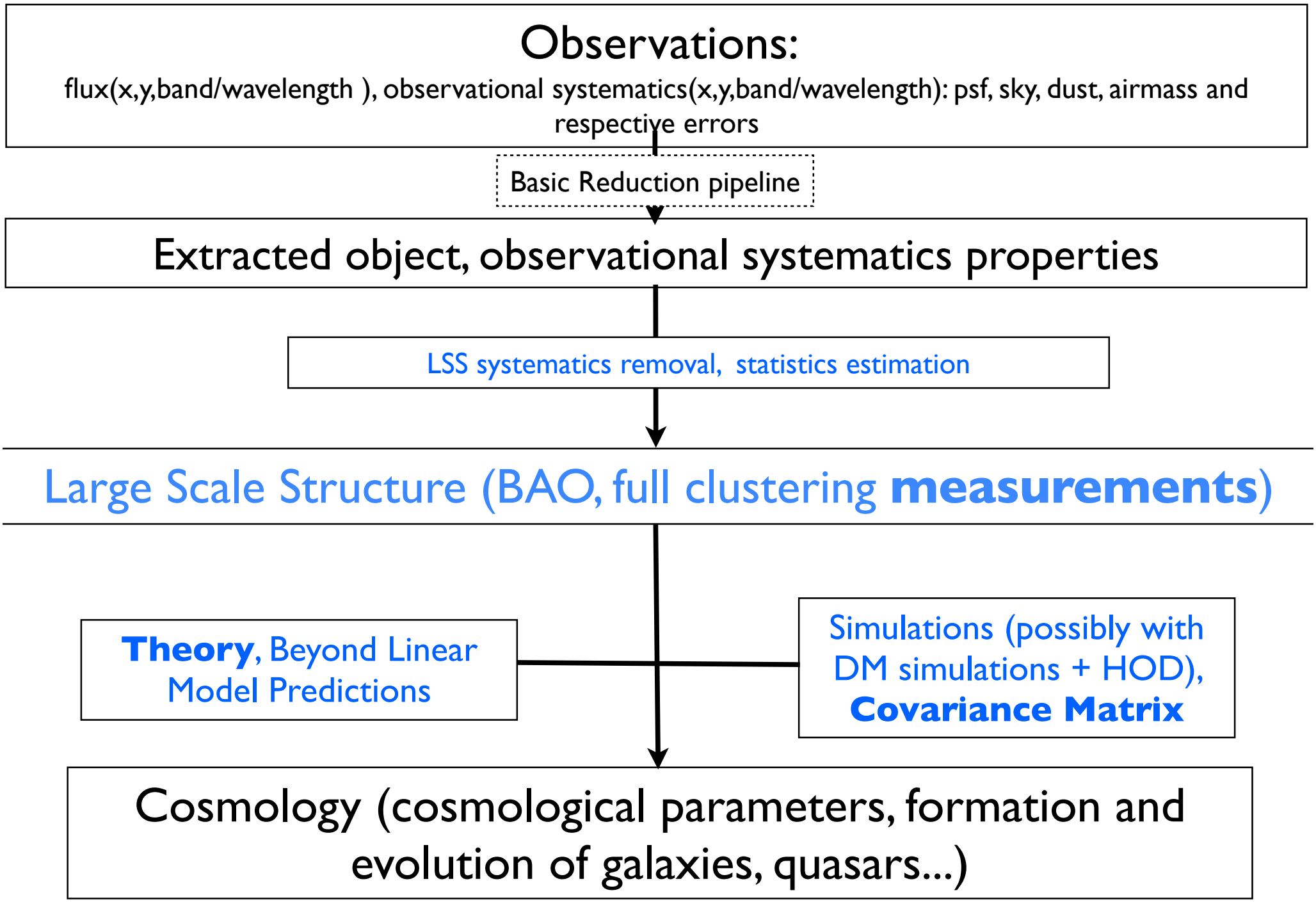


If we can pass through all the challenges...

and there are more I didn't mention...

for example: photo-z determination, bias modeling, potential BAO fitting systematics ...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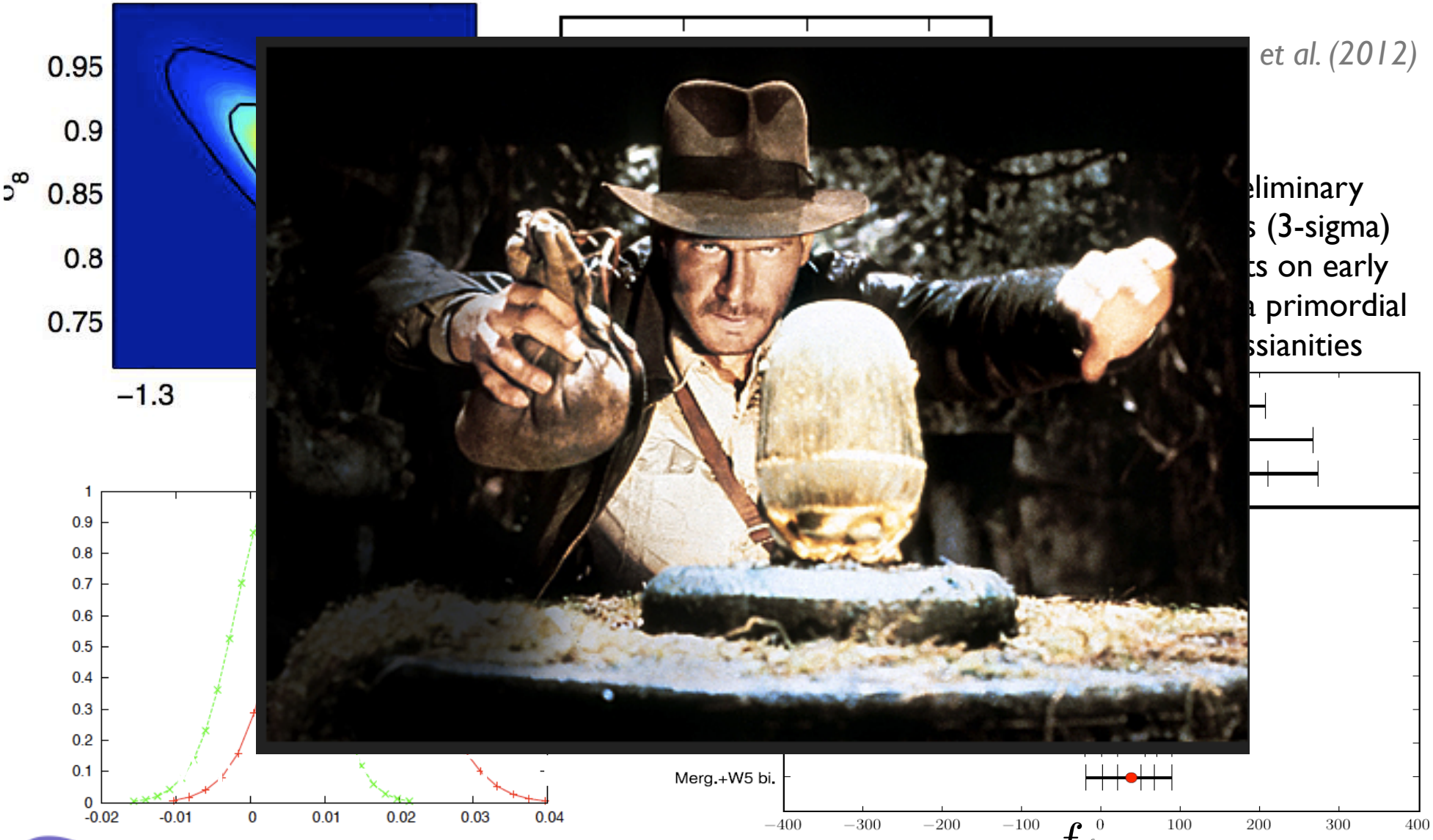
Robust Cosmological Constraints from LSS



et al. (2012)

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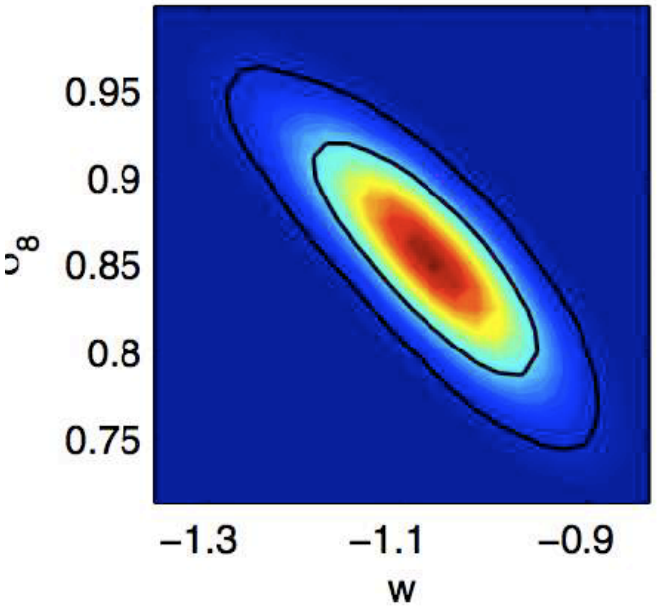
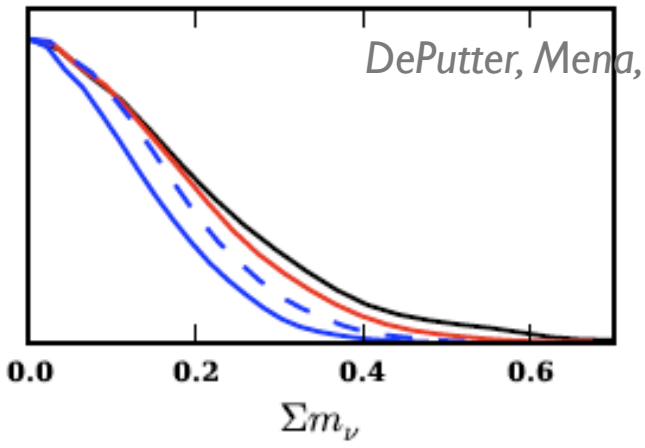
SDSSIII

SH, Myers, Slosar et al. (in prep)

SH, Cuesta, Seo, Ross, DePutter et al. (2012)

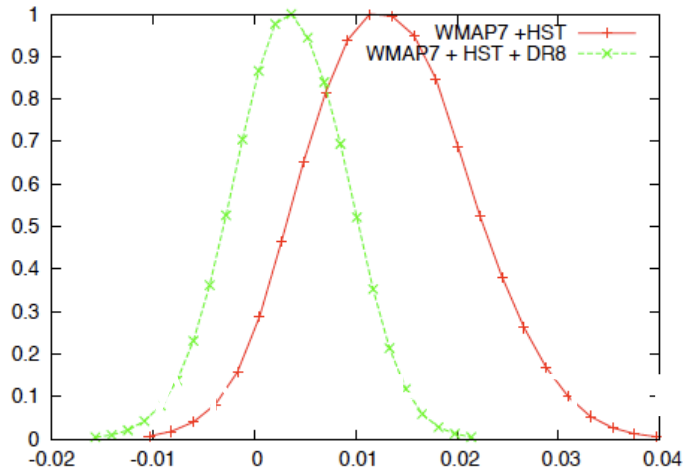
Cosmological Constraints from the overall shape

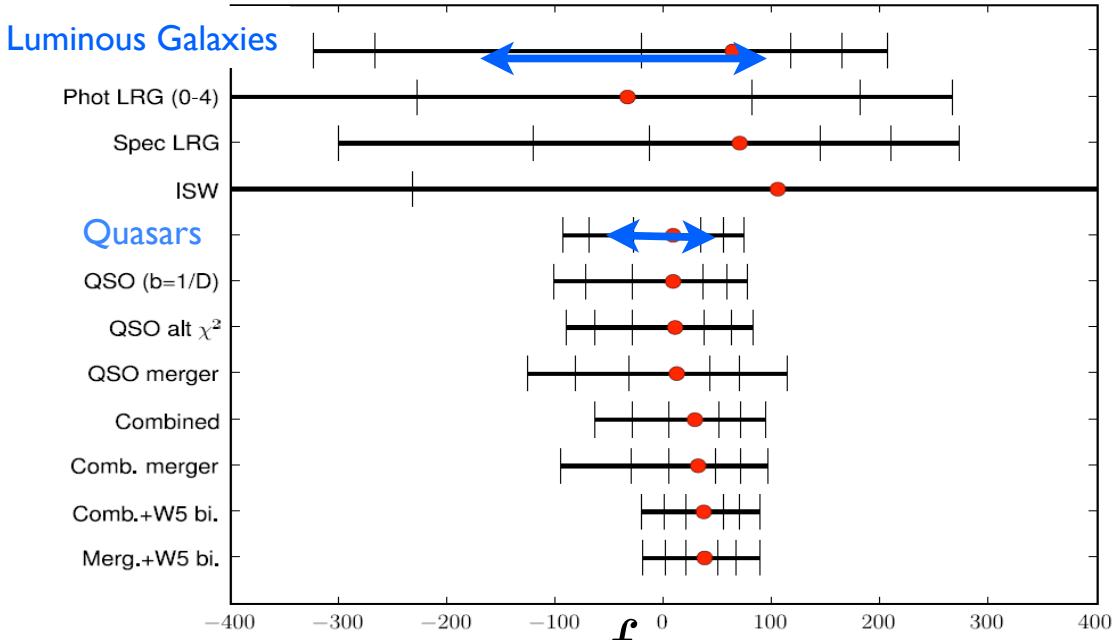




DePutter, Mena, Guisarma, SH, Seo et al. (2012)

New preliminary constraints (3-sigma) Constraints on early Universe via primordial non-gaussianities



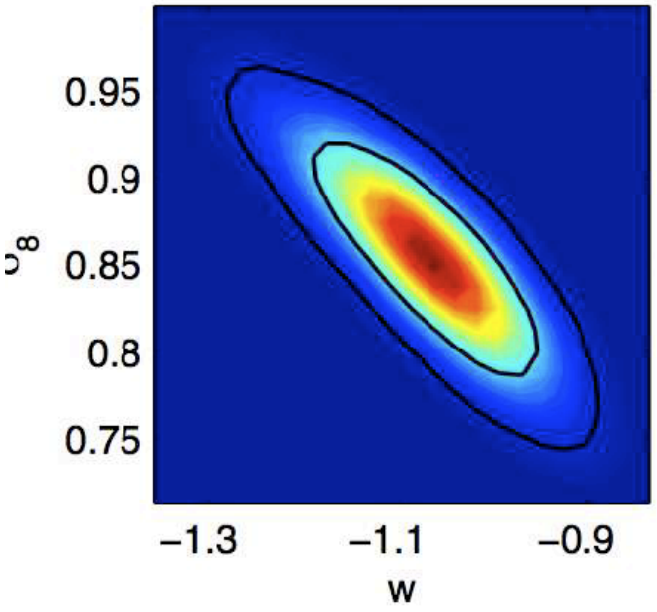


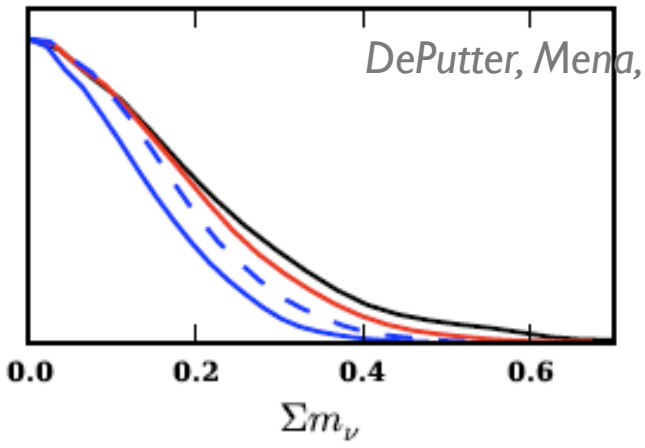
SH, Myers, Slosar et al. (in prep)

SH, Cuesta, Seo, Ross, DePutter et al. (2012)

SDSSIII

Cosmological Constraints from the overall shape





DePutter, Mena, Guisarma, SH, Seo et al. (2012)

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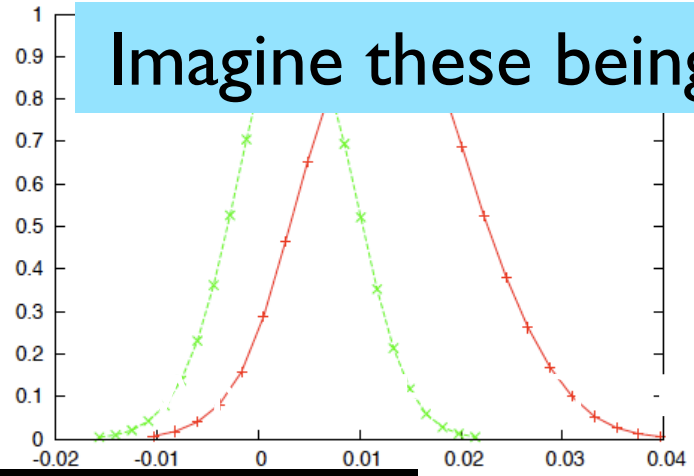

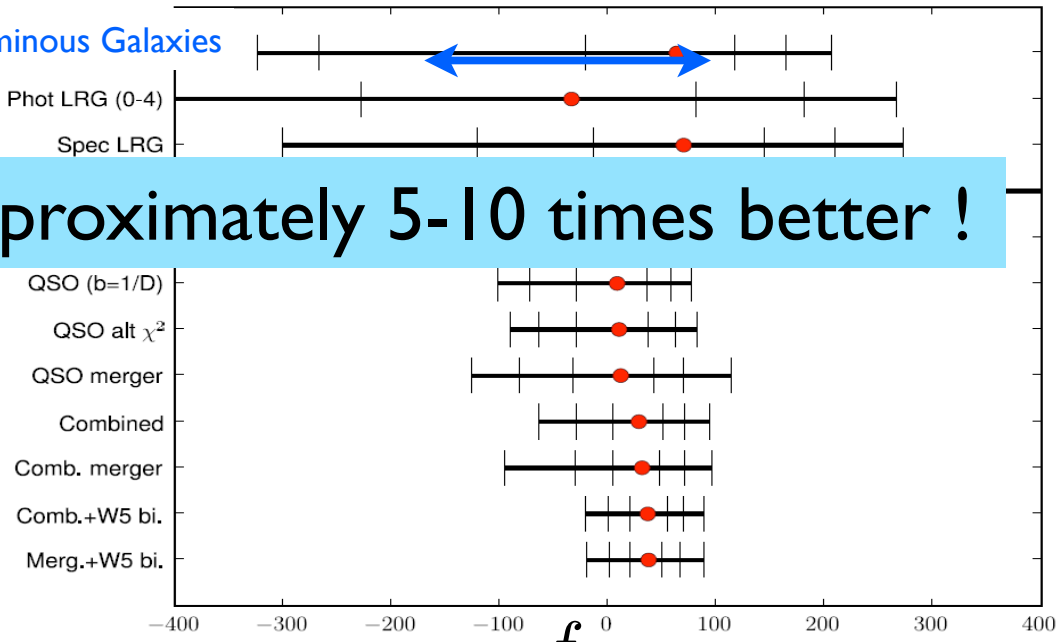

Imagine these being approximately 5-10 times better !

SH, Myers, Slosar et al. (in prep)

SH, Cuesta, Seo, Ross, DePutter et al. (2012)

Large Synoptic Survey Telescope